



# **Supersonic Particle Deposition (SPD)**

## **Applications and R&D at ARL**

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Weapons & Materials Research Directorate**

**22 March 2005**

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# SPD Applications At ARL

- |                                      |                        |
|--------------------------------------|------------------------|
| 1. EMI Coatings for HMMWV Shelter    | General Dynamics       |
| 2. Aluminum Coatings for Mg Housings | Sikorsky Aircraft      |
| 3. Advanced Med. Cal. Munitions      | ARL R&D                |
| 4. Fuel Cells                        | ARL R&D                |
| 5. Heat Exchangers                   | ARL R&D, U of Maryland |
| 6. Armor Tile Encapsulation          | ARL R&D, PennState     |
| 7. W-Cu Coatings (Classified)        | ARL-R&D                |

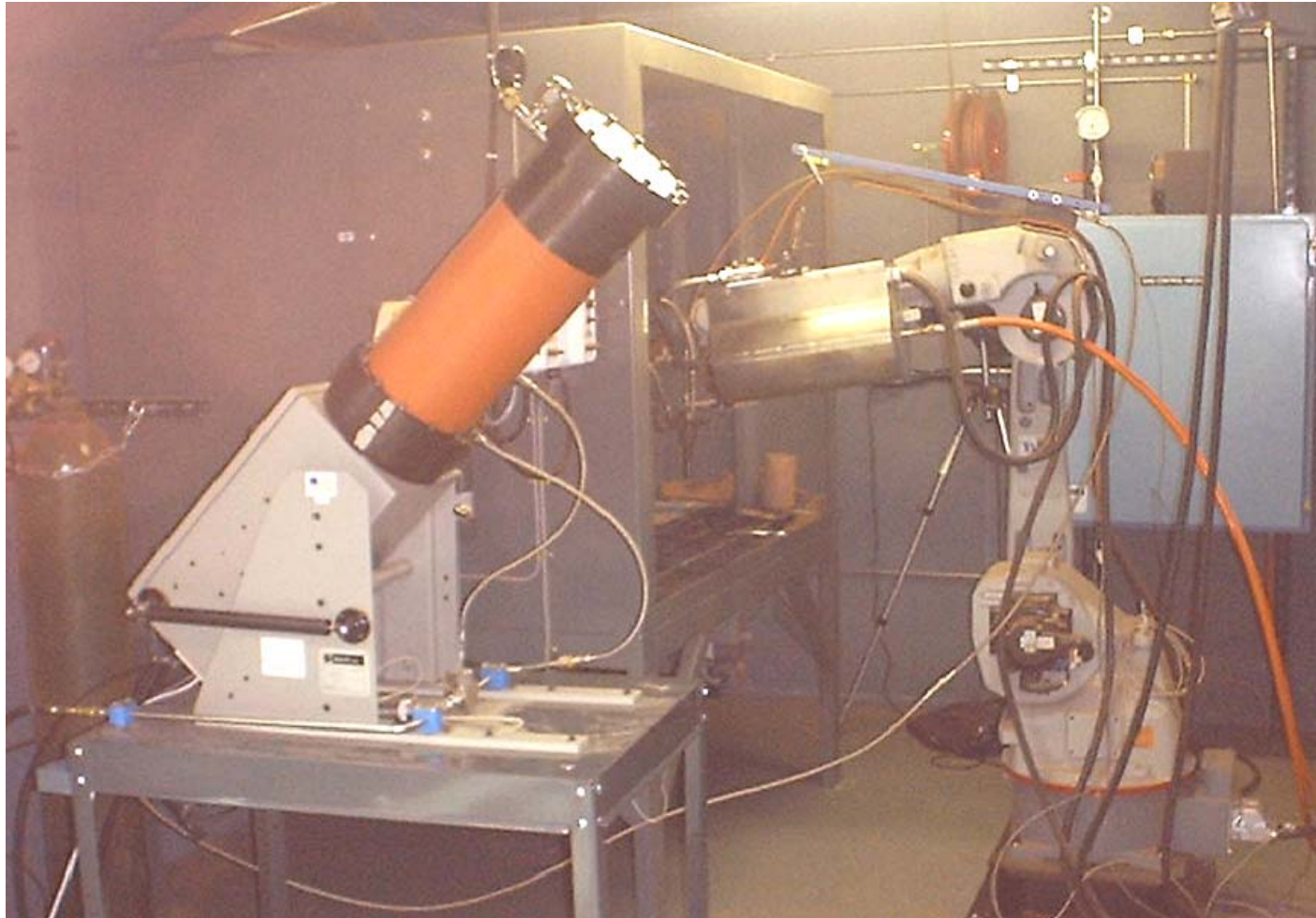


# ARL SPD Research Team

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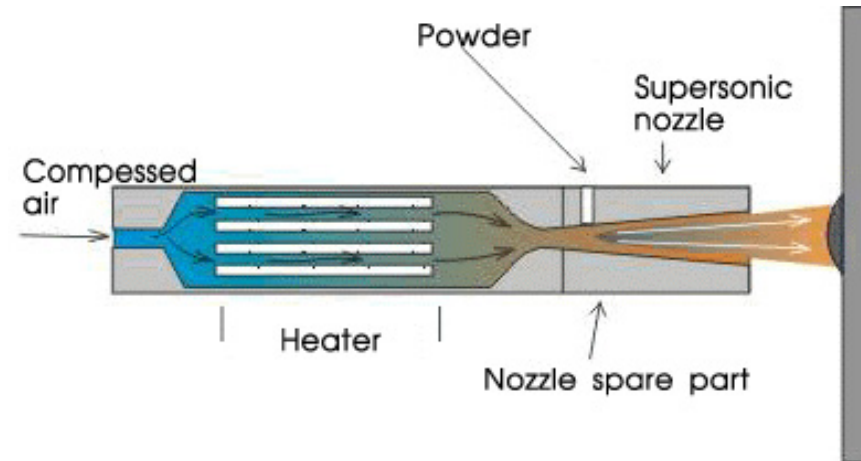


# Army Research Laboratory SPD System





# Portable SPD



Downstream Powder Feed

Portability/Field Repair

Slightly Lower Particle Velocity

Special Powder Formulation

ARL Has Two Portable Systems

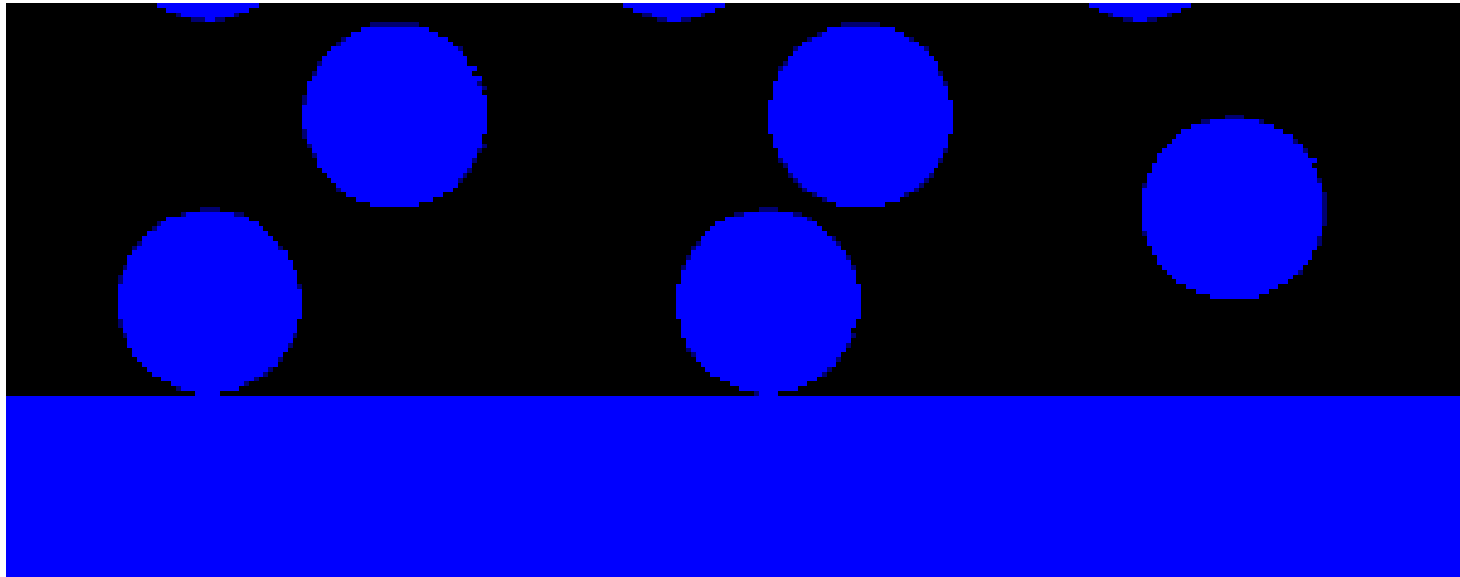


# SPD Advantages

- **Low temperature**
  - Solid State Process
  - Low residual stresses
  - Minimal grain growth
- **Little oxidation**
  - good electrical/thermal conductivity
  - electrical conductivity: 80% of OFHC Copper
- **High deposition rates and efficiencies**
  - rates - up to 20 kg/hr.
  - efficiencies generally 50 - 80%
- **Wide variety of coating materials and substrates**
  - Al, Zn, Sn, Cu, Ni, Ti, Ta, Co, Fe, Nb, Mo, W.

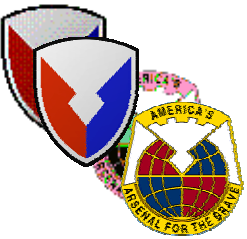


# Particle/Substrate Interaction\*



\*from H. Assadi, [www.modares.ac.ir/eng/ha10003/CGS.htm](http://www.modares.ac.ir/eng/ha10003/CGS.htm)





# EMI Shielding for HMMWV Shelter and Al Coating for Helicopter Mg Housings-FY05 Effort

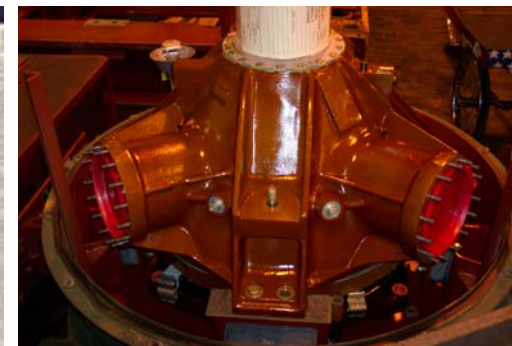
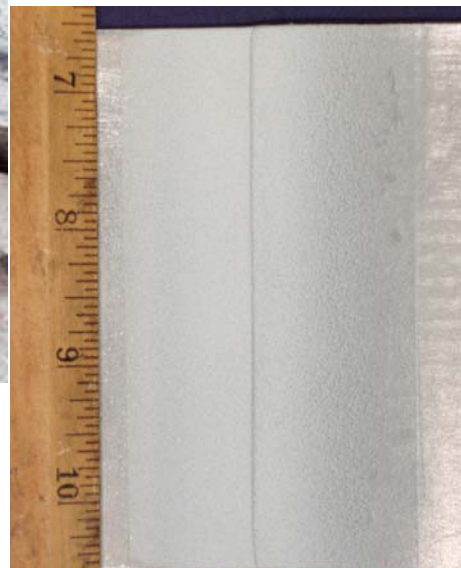
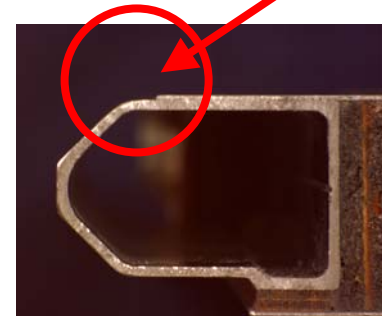
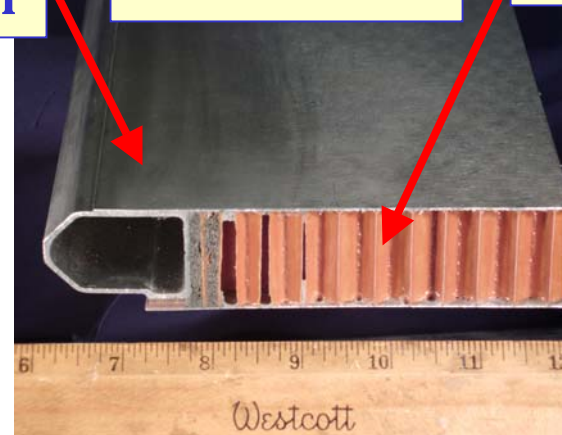


6061-T6 Al

Cross-section

Composite

Lap joint



Supersonic Particle Deposition

AL EMI Coating on lap joint seam

The main rotor transmission gearbox in the UH60 Blackhawk.



# HMMWV-mounted Lightweight Shelter



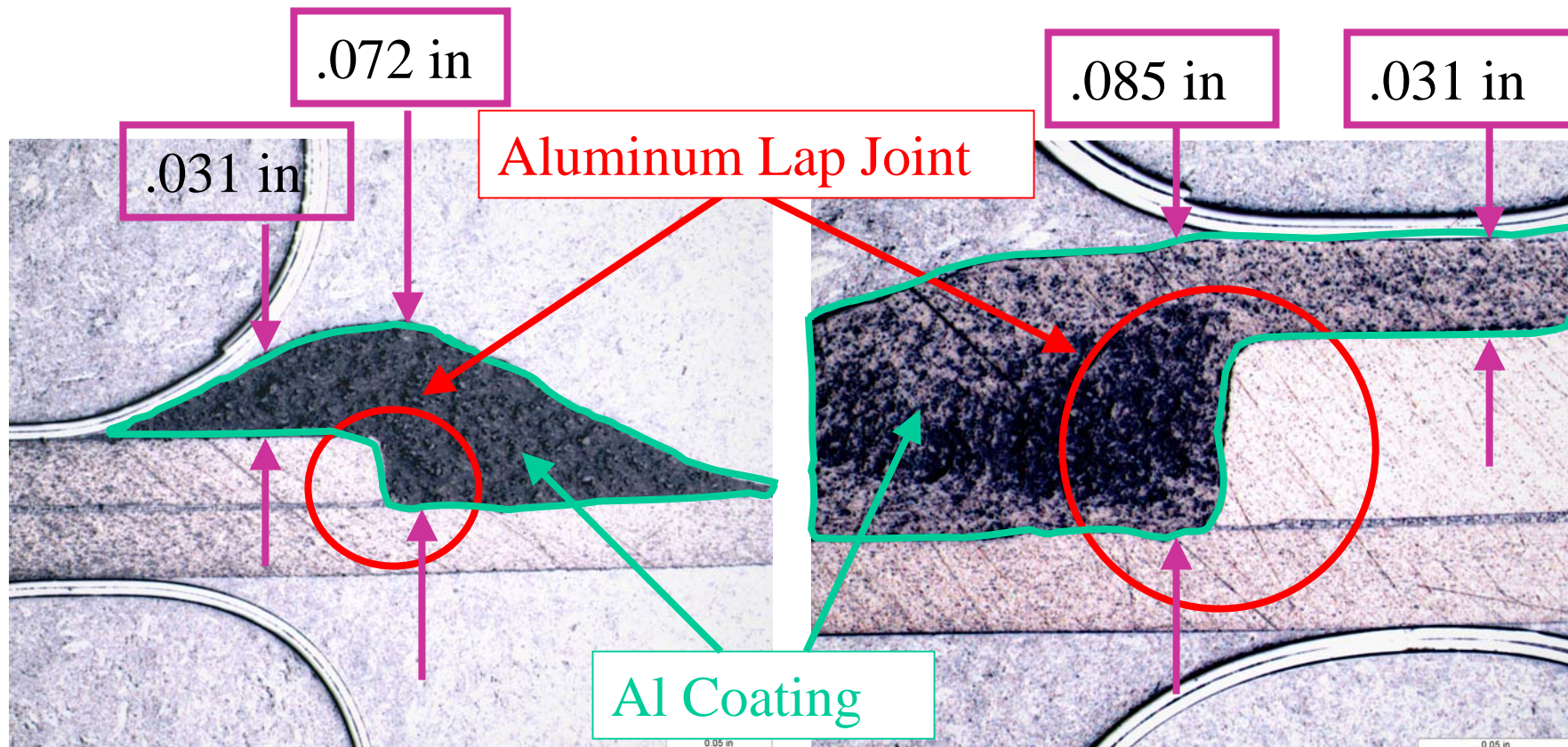




# Metallographic Cross-Sections of EMI Coatings

Supersonic Particle Deposition

High Velocity Oxy Fuel

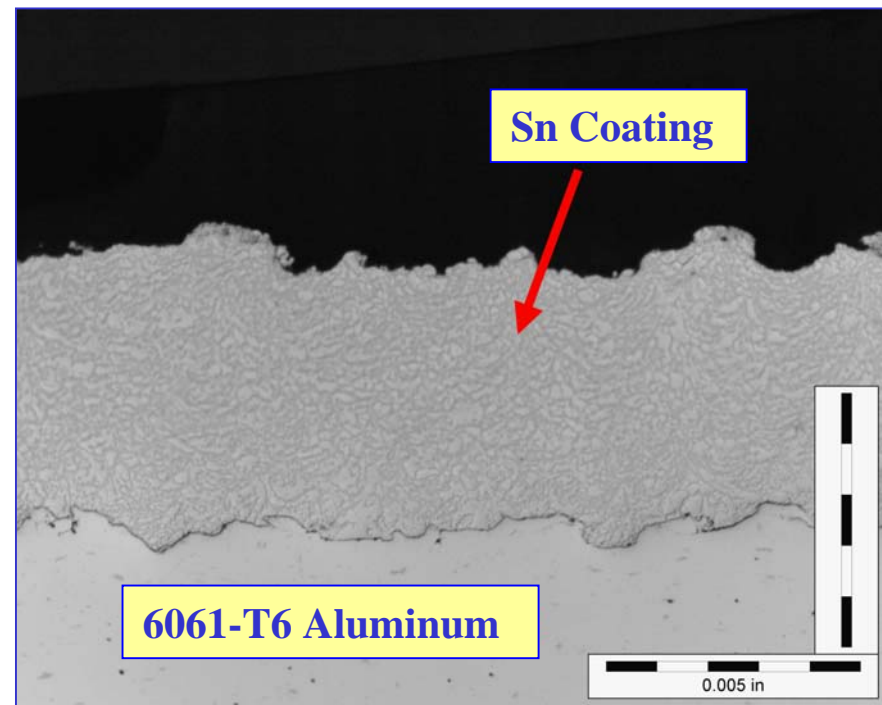
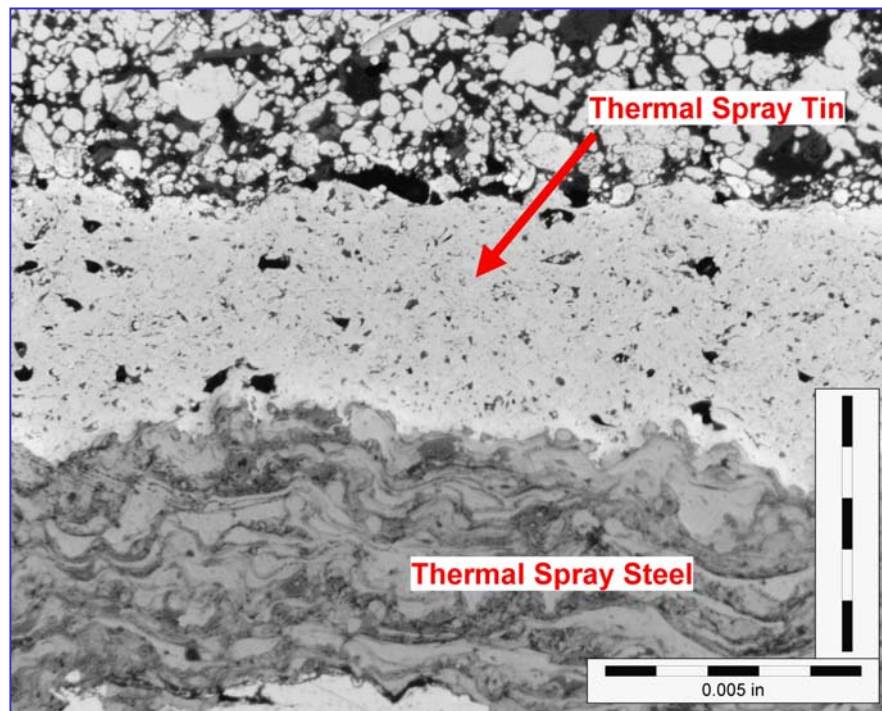


Hand-held portable SPD System

Automated HVOF System



# Flame Spray vs. Supersonic Particle Deposition



Flame Spray Sn and Steel Coating

SPD Sprayed Sn Coating

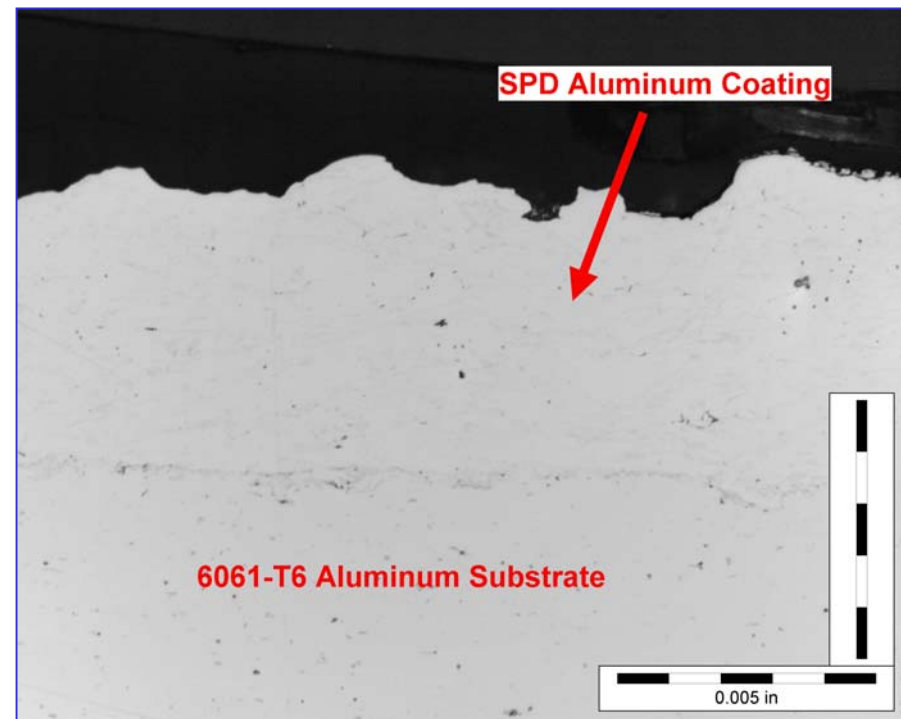
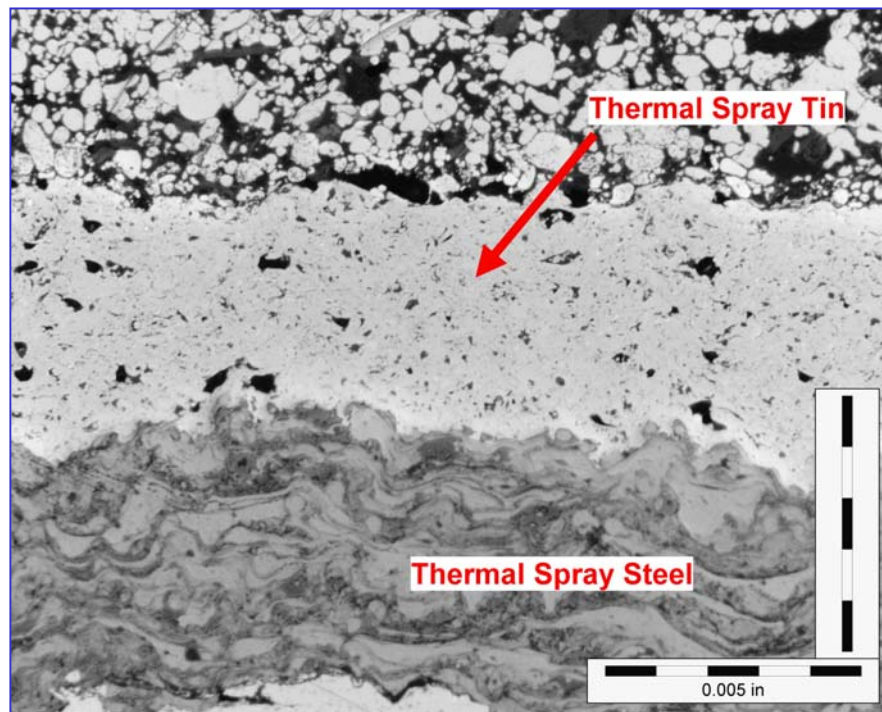
~12.2% Porosity

~.18% Porosity





# Flame Spray vs. Supersonic Particle Deposition



Flame Spray Sn and Steel Coating

SPD Sprayed Al Coating

~12.2% Porosity

~.83% Porosity



# Portable SPD Application





## Cost of SPD

### Cost to operate Portable SPD System

Utilizes regular air at no cost.

Aluminum powder cost is \$9.70/lb.

One quarter pound of powder was used to coat the test piece

It took 1.5 min. to spray a 1ft section which equates to ~\$2.43/ft.

This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

**\$2.43/ft. for .031 in coating or \$.60/ft. for .008 in coating**



## Cost of HVOF Coating

Cost to operate Metco Diamond Jet HVOF System

Hydrogen - \$8.17 per bottle \$50/hr. Oxygen - \$5.25 per bottle \$15/hr.

Aluminum powder cost is \$13.27/lb. @30grams/min. \$53/hr.

Traverse rate 600 mm/sec or 23.6 inches/sec.

40 passes is what was used to spray the test piece.

It took 1 min. to spray a 2ft section which equates to \$2.05 or ~\$1.00/ft. This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

**\$1.00/ft. for .031 in coating or \$.25/ft. for .008 in coating**



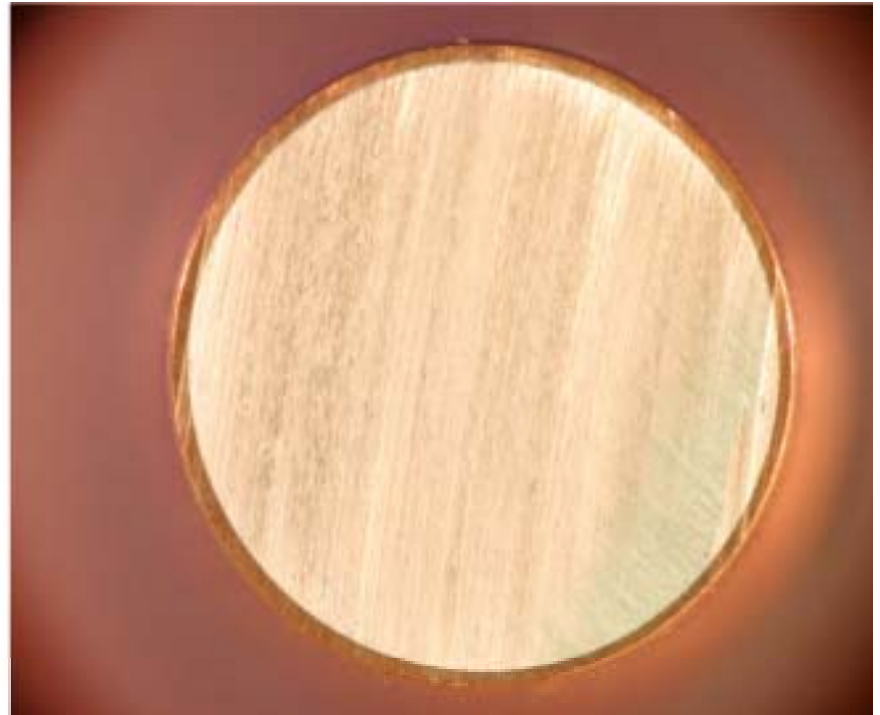
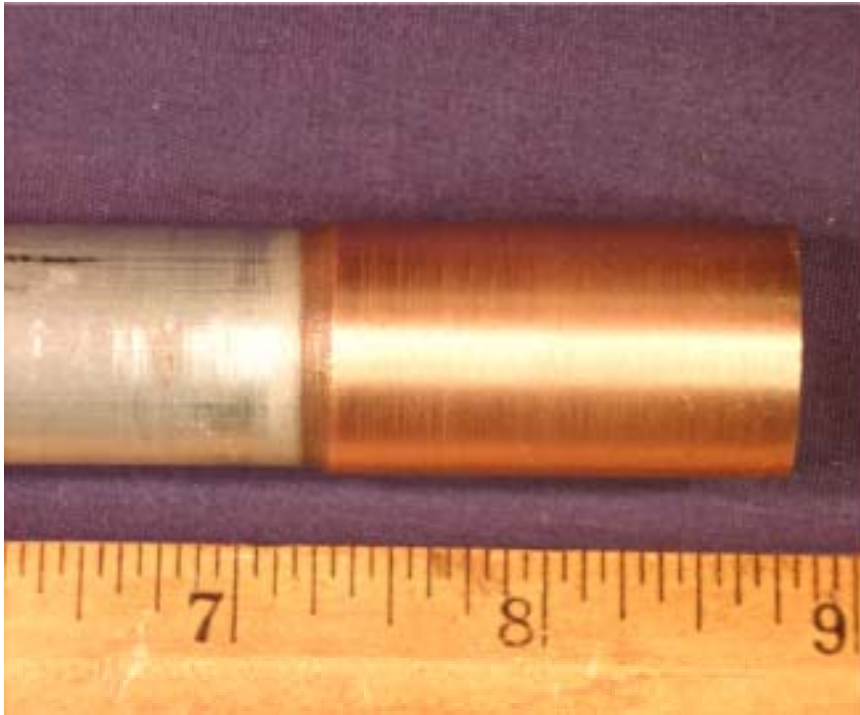


## Conclusions SPD for HMMWV

- SPD can provide EMI Coatings for the HMMWV superior to Thermal Spray in terms of porosity and conductivity (fewer oxides).
- SPD can easily deposit onto lap joints.
- TAS could be used in conjunction with SPD for butt joints.
- SPD recommended for field repair and for production.



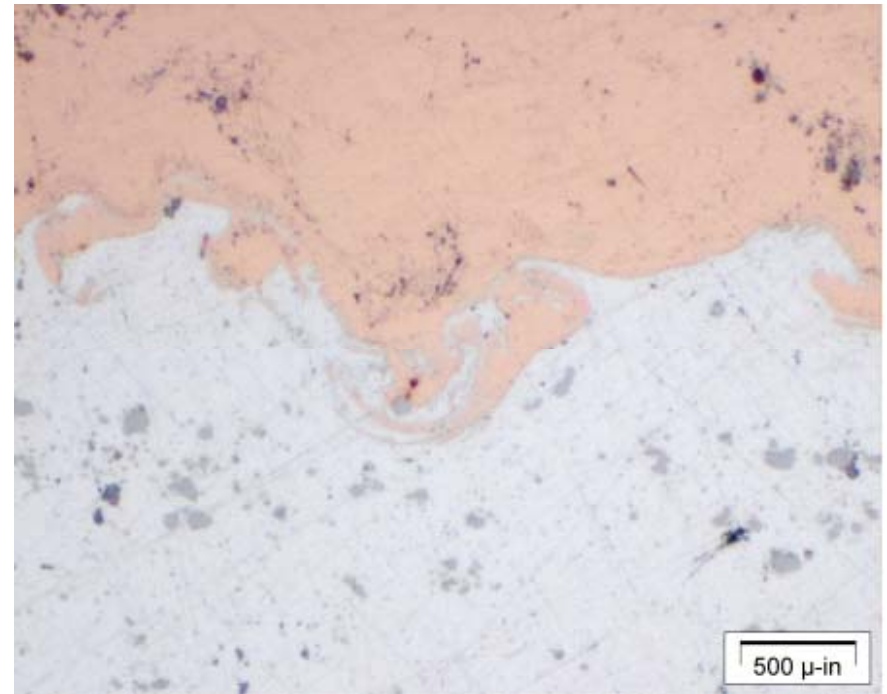
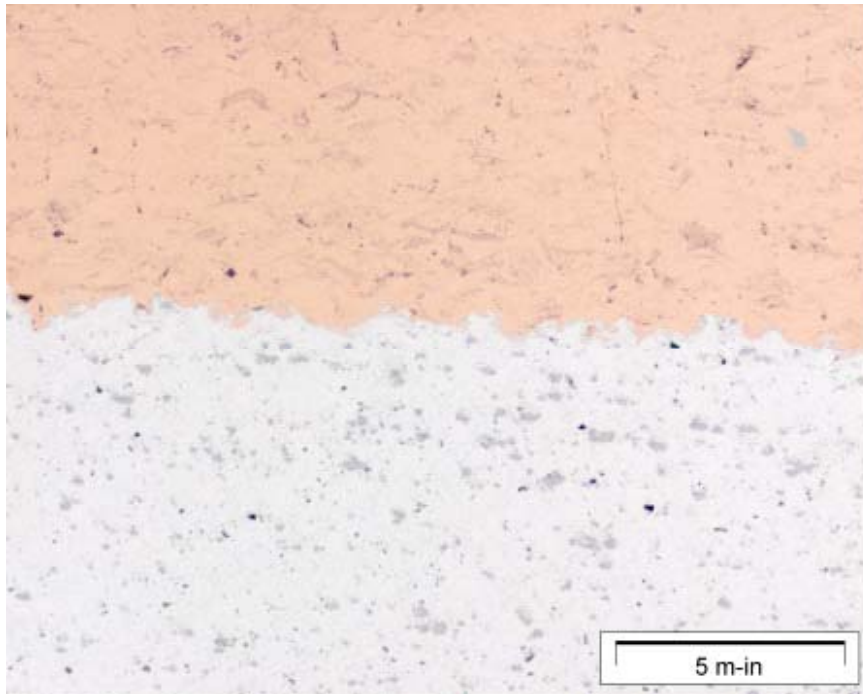
# Copper Deposited On Aluminum Rod Advanced Medium Caliber Munitions





# Magnified Interface

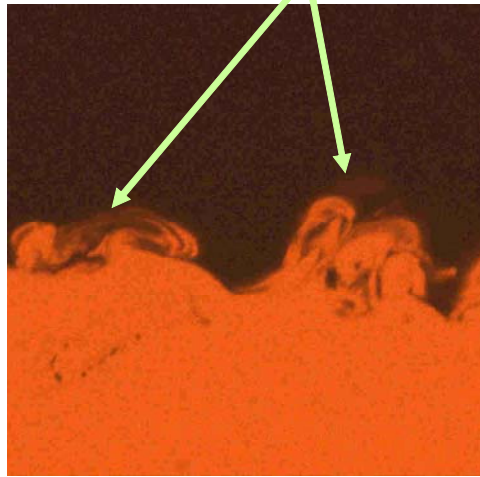
## Super Plastic Agglomerated Mixing (SPAM)



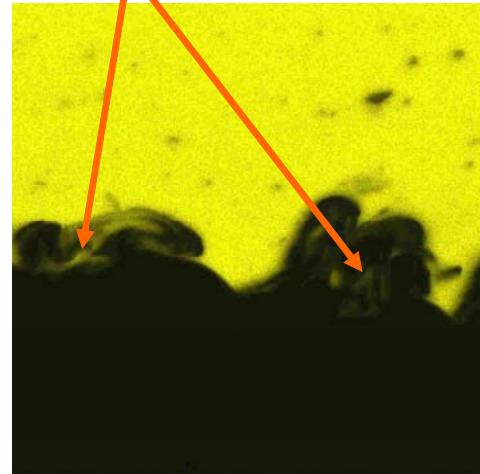


# EDS X-ray Mapping of SPAM

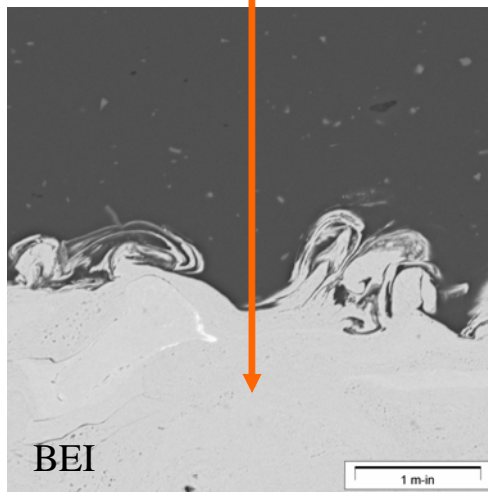
Forced mixing of copper and aluminum.



Copper SPD Coating

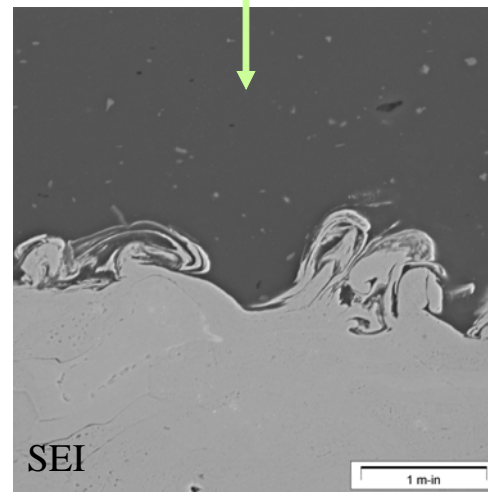


Aluminum Substrate



BEI

1 m-in



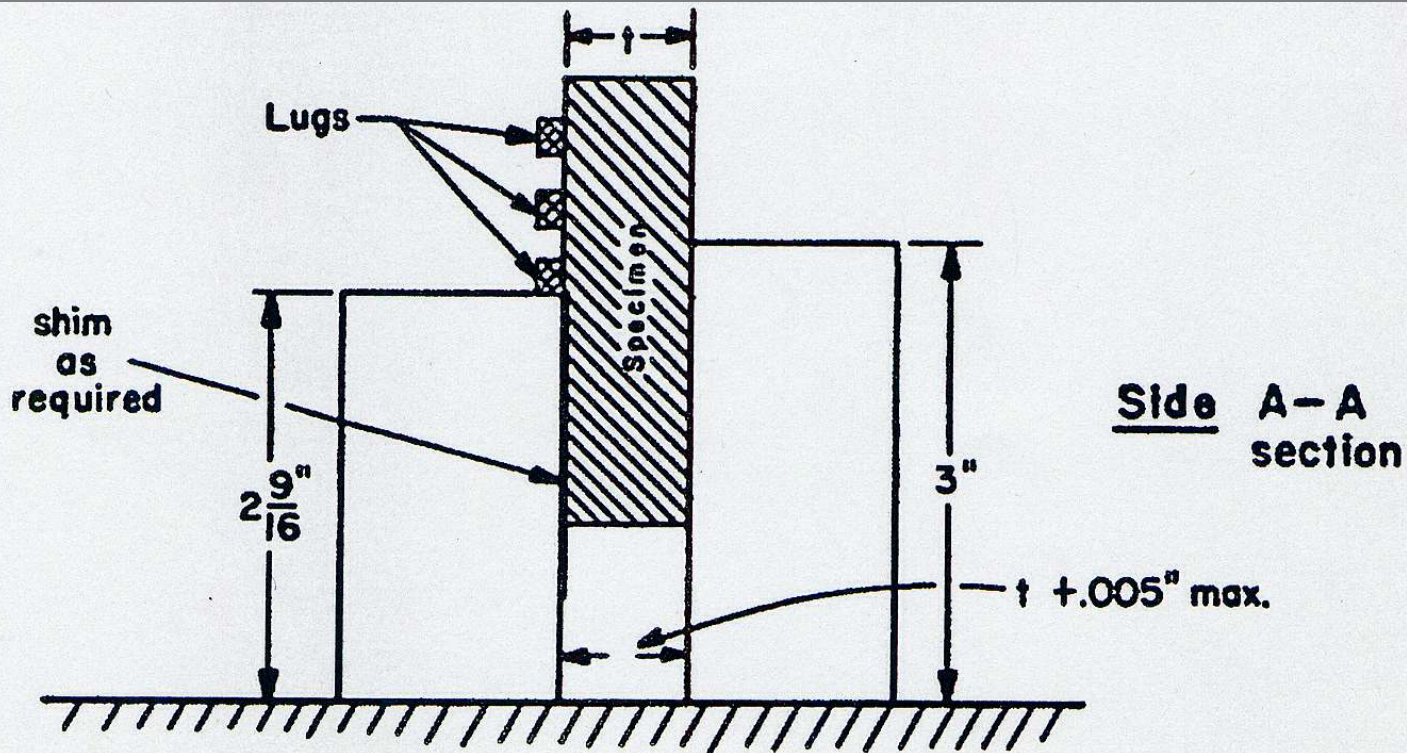
SEI

1 m-in





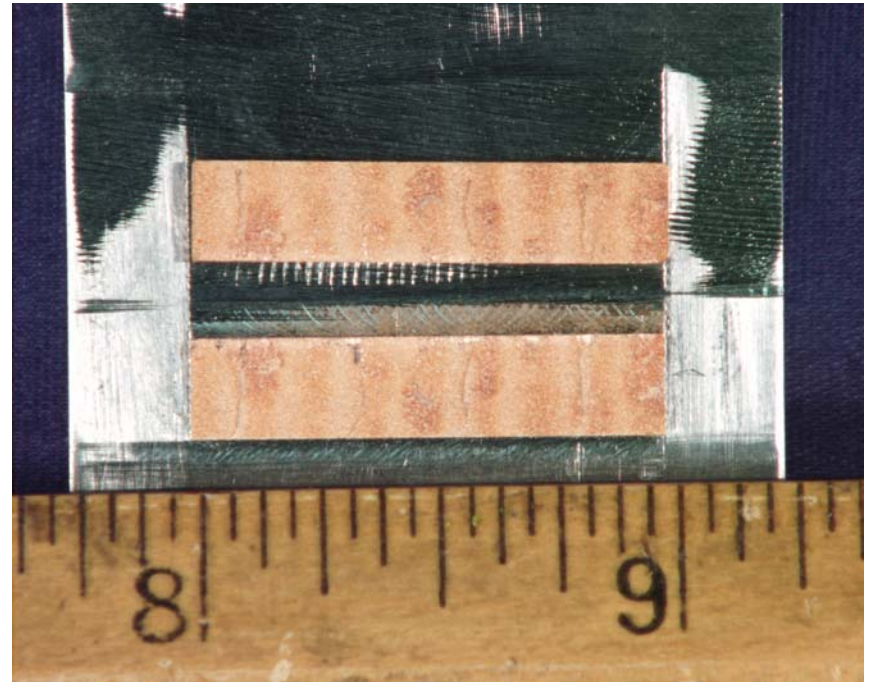
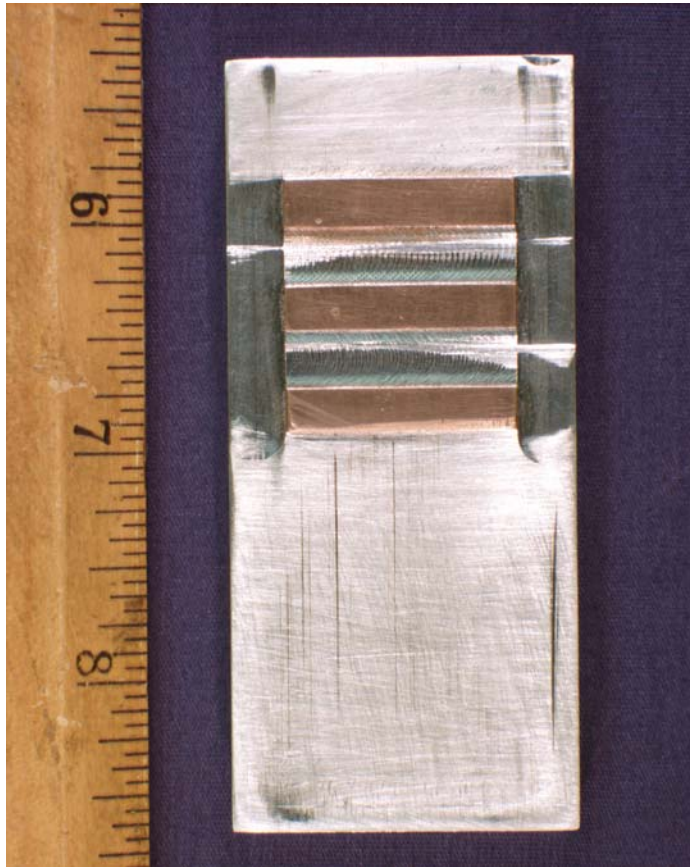
# Triple Lug Shear Test Fixture



MIL-J-24445A

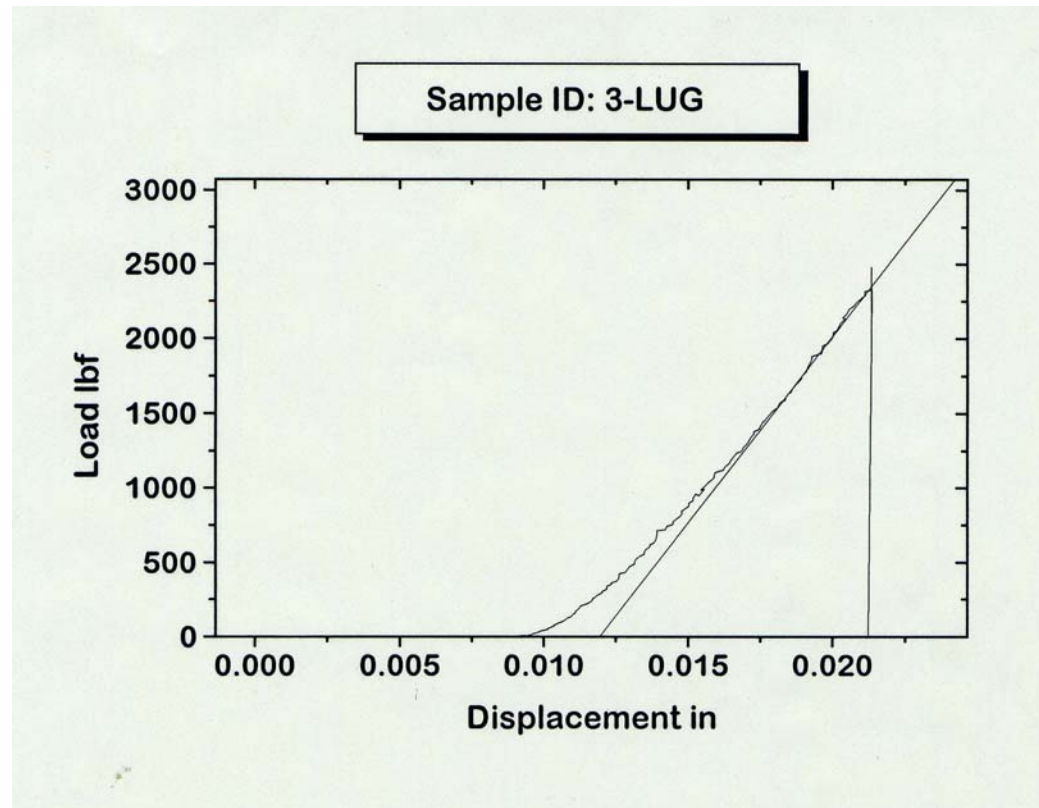


# Triple Lug Shear Test Sample





# Copper on Aluminum



Shear Test Bond Strength = 11,650 psi



# Shear Test Results

## (Triple Lug Shear Test)

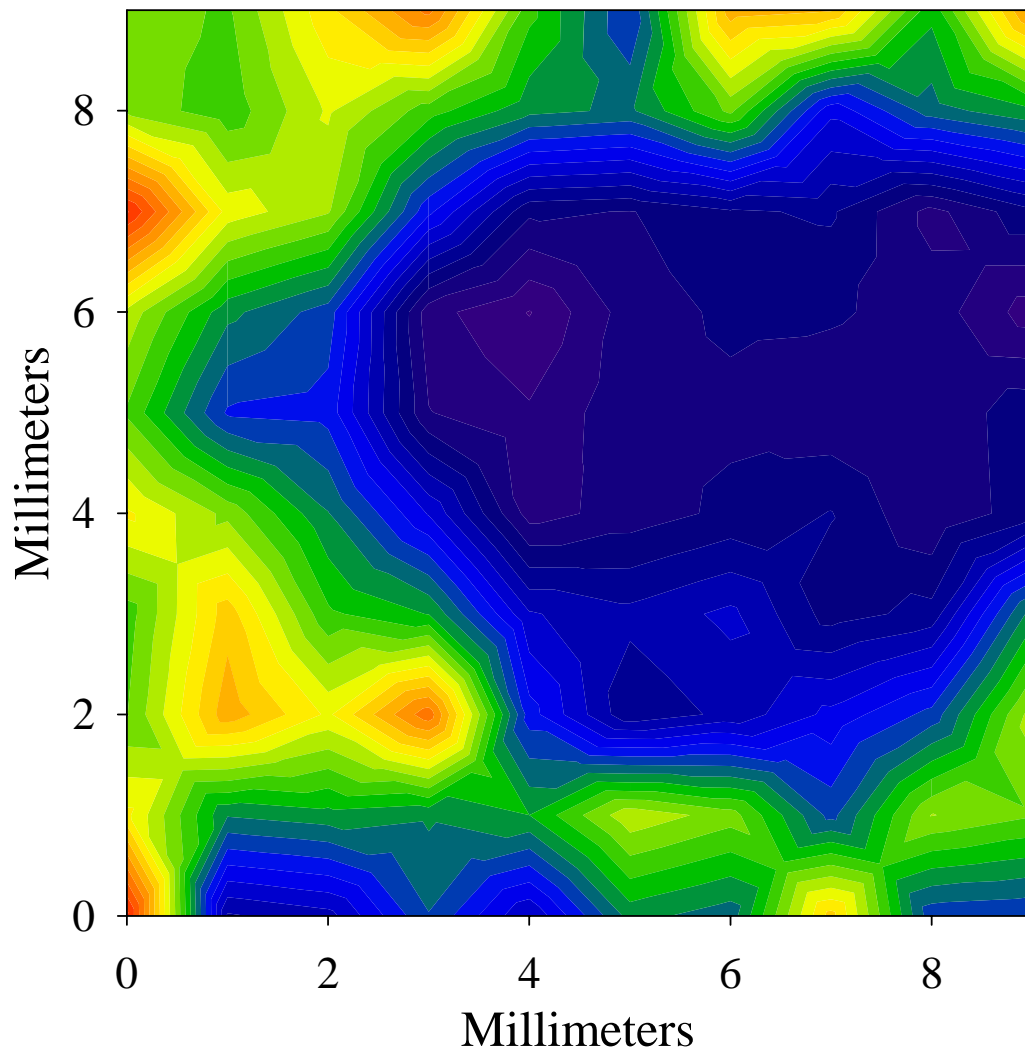
Trial	Pressure psi	Temperature degree C	Stand-off mm	Speed mm/sec	Feed rate gm/min	Shear strength psi
1	280	450	35	50	7	5347
2	280	350	15	50	28	6072
3	380	450	35	10	28	6683
4	380	350	15	10	7	10057

Failure Mode = Cohesive

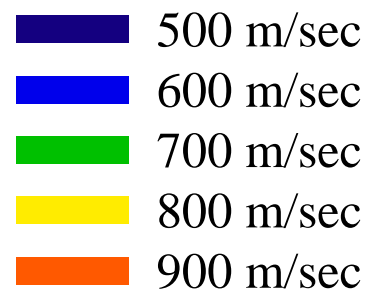




# Particle Velocity Distribution



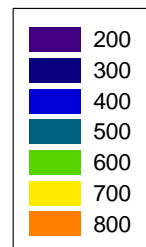
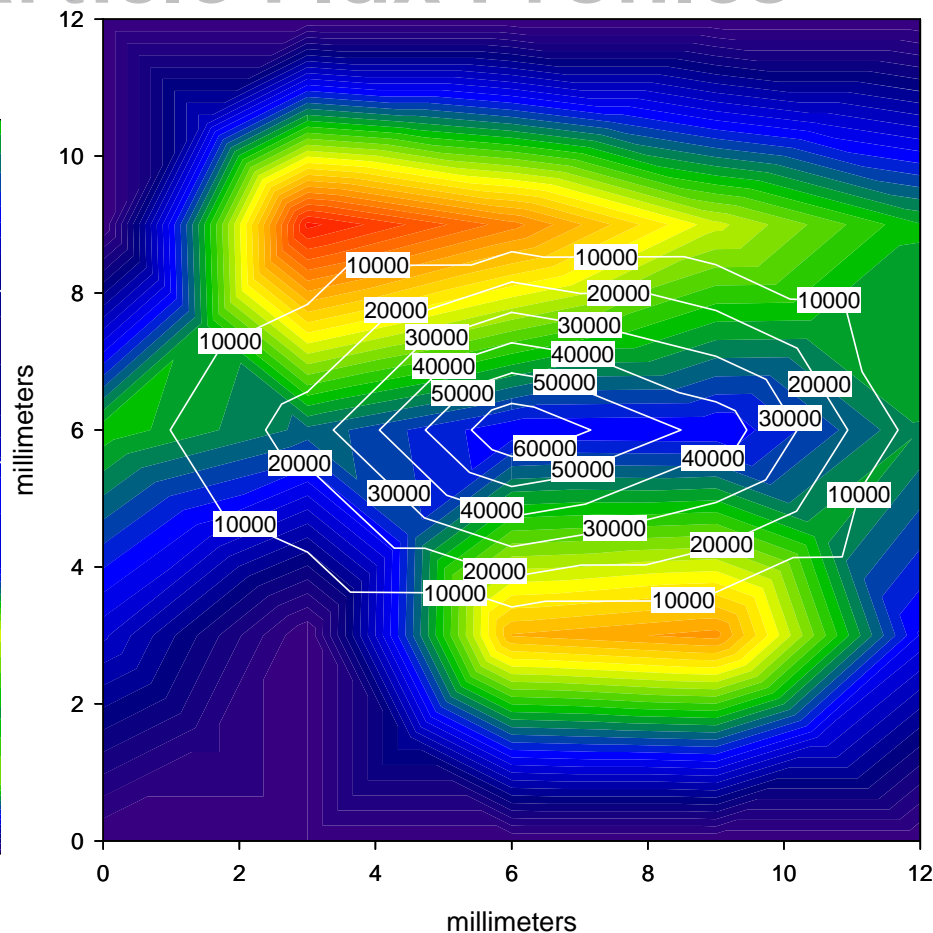
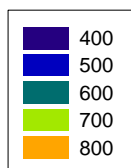
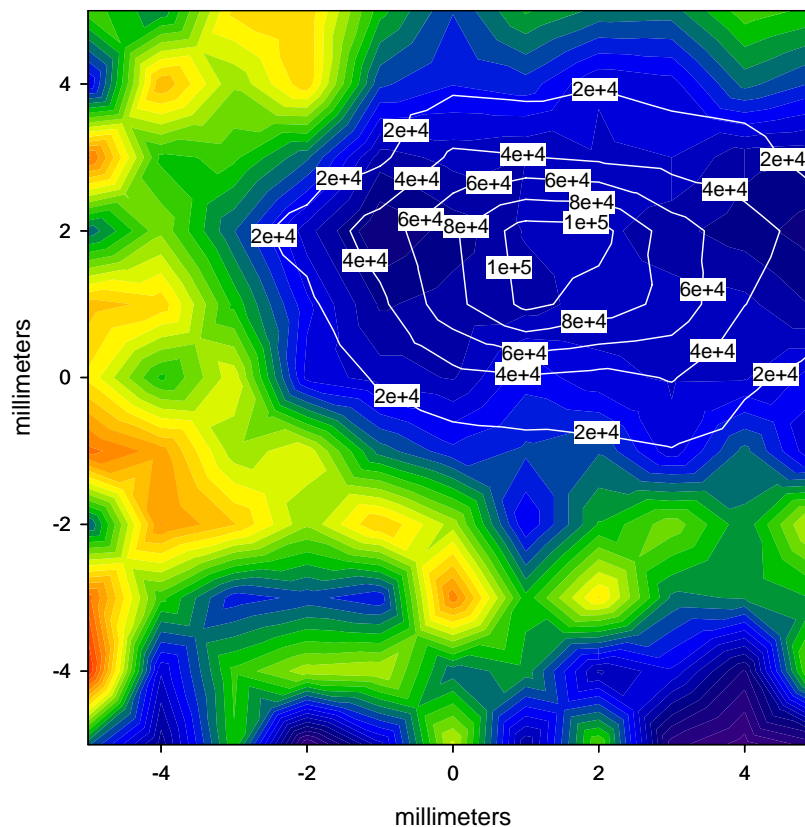
**20 micron copper particles**  
**25 mm downstream**  
**400 psi, 400 C N<sub>2</sub> gas**





# SPD and DYMET

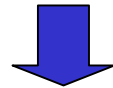
## Velocity and Particle Flux Profiles



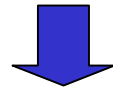


# Modeling Efforts

Nozzle flow equations are used to calculate gas velocity and temperature within the nozzle.



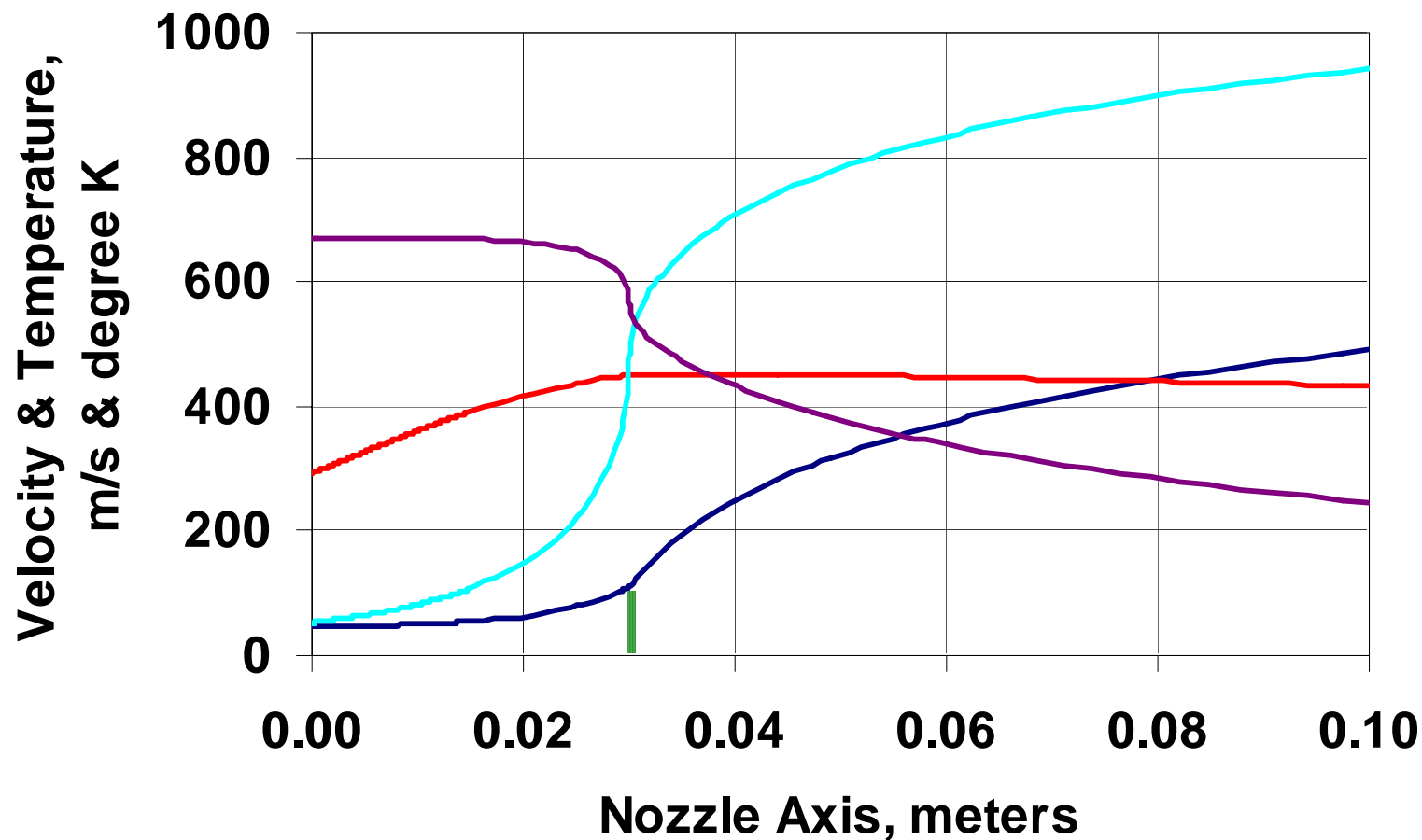
The resulting particle velocity and temperature are then calculated by gas-particle drag and heat transfer.



An empirical relationship between critical velocity and particle material characteristics is used to determine deposition efficiency.



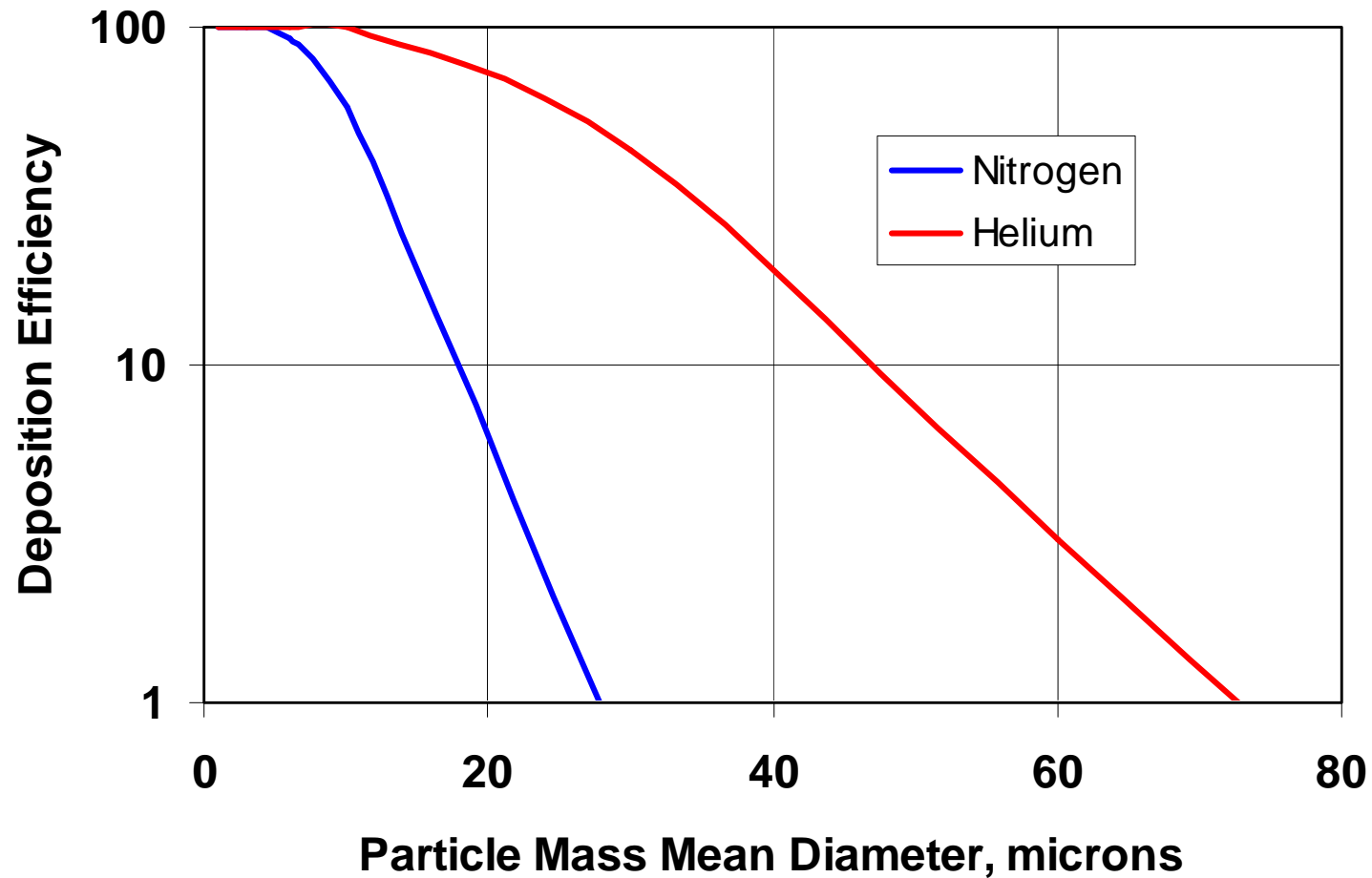
# Typical Calculation



— particle velocity — particle temp — nozzle throat  
— gas velocity — gas temp

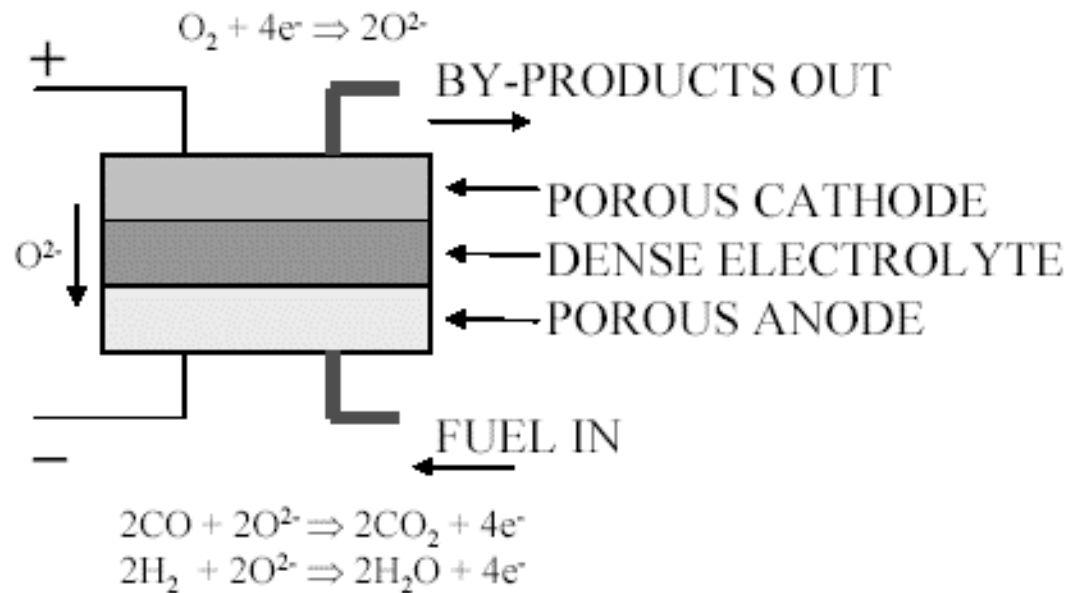
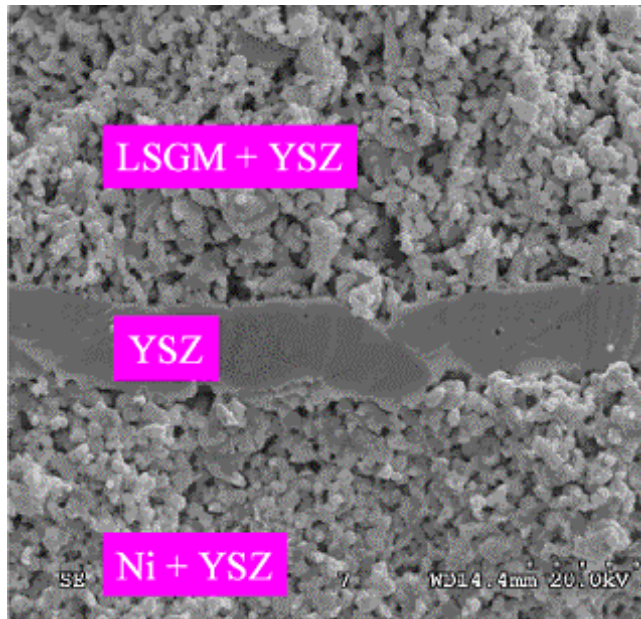


# Effect of Particle Diameter on Deposition Efficiency





# SPD Fuel Cell Concept





# SOFC Anode Construction

## Conventional Method

- Tape cast YSZ with organic filler
- Bake out organic
- Deposit NiO
- Reduce to Ni with hydrogen

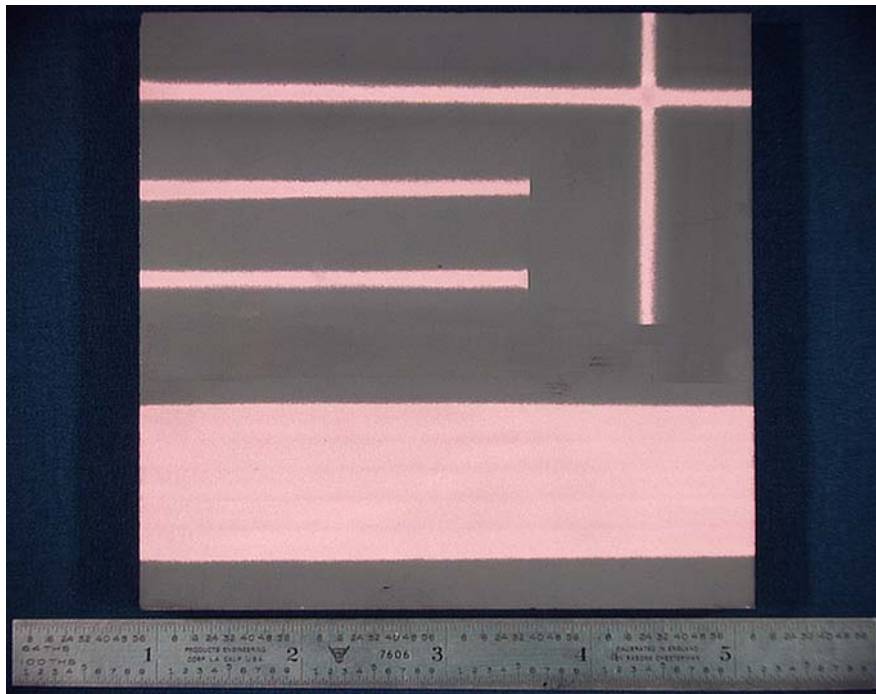
## SPD Deposition

- Mix YSZ and nickel powders
- Deposit mixture with SPD

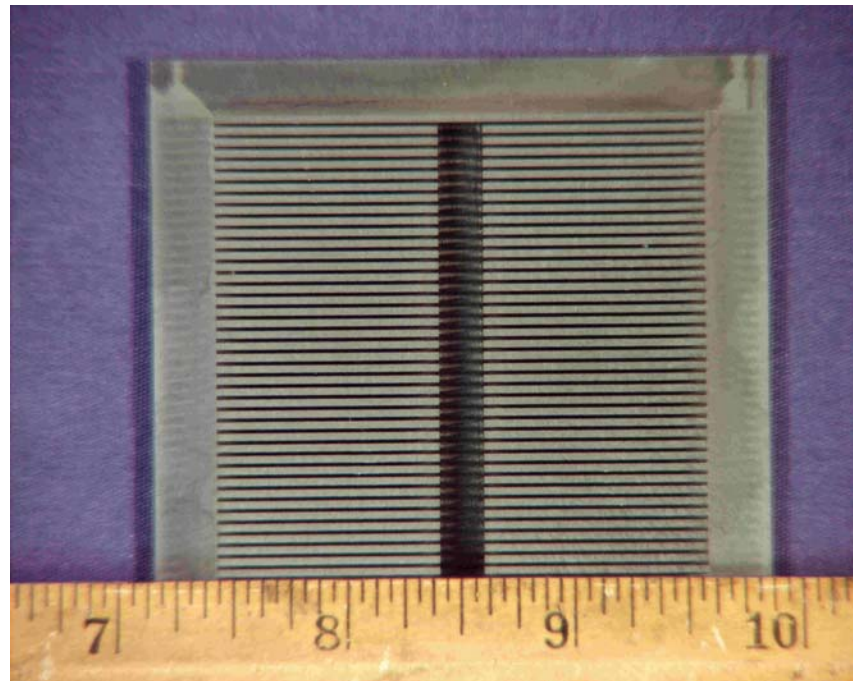




# Improved Heat Exchanger



Copper on SiC



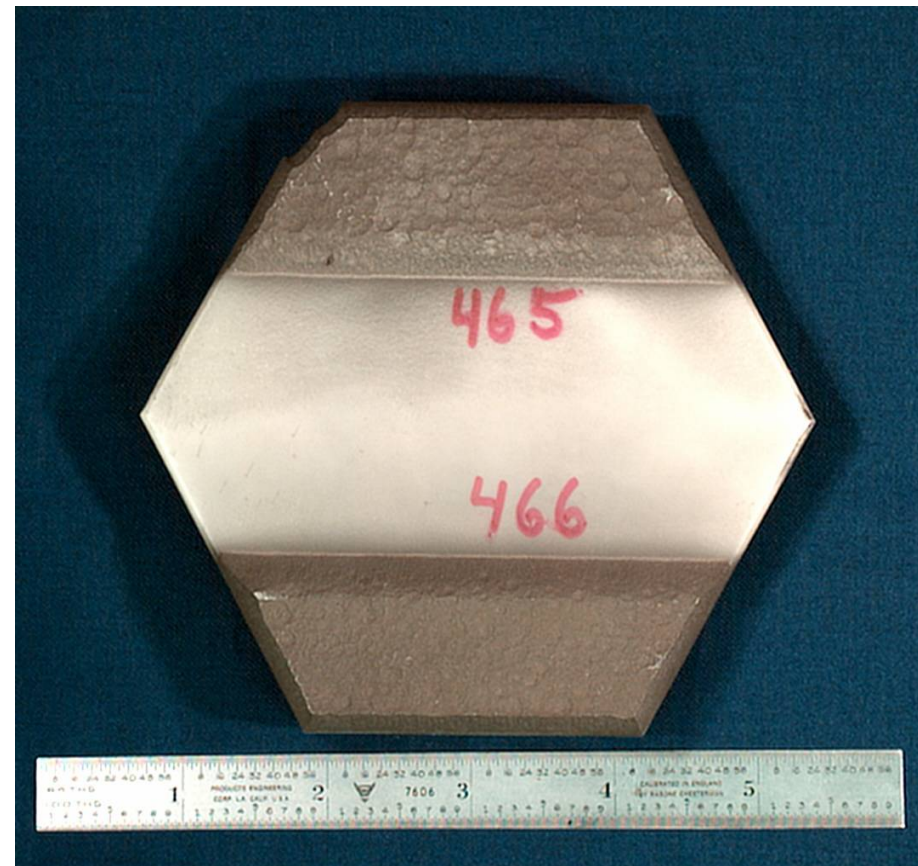
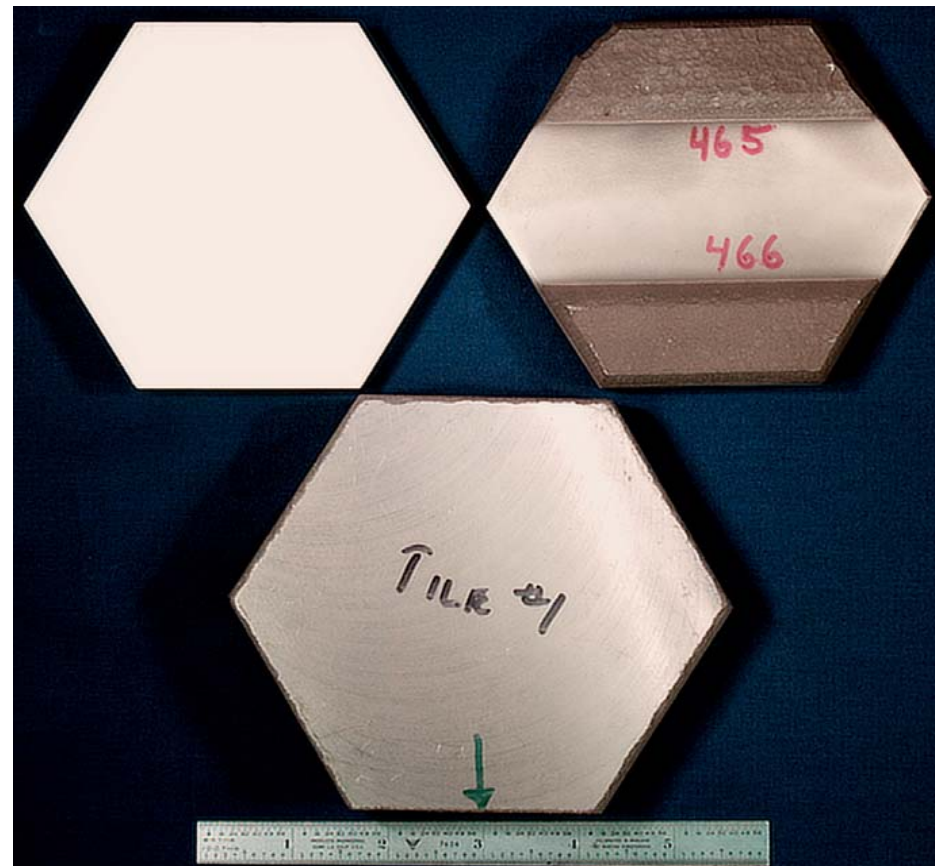
Al-SiC heat exchanger

Other ceramics include alumina & aluminum nitride





# Develop SPD Parameters



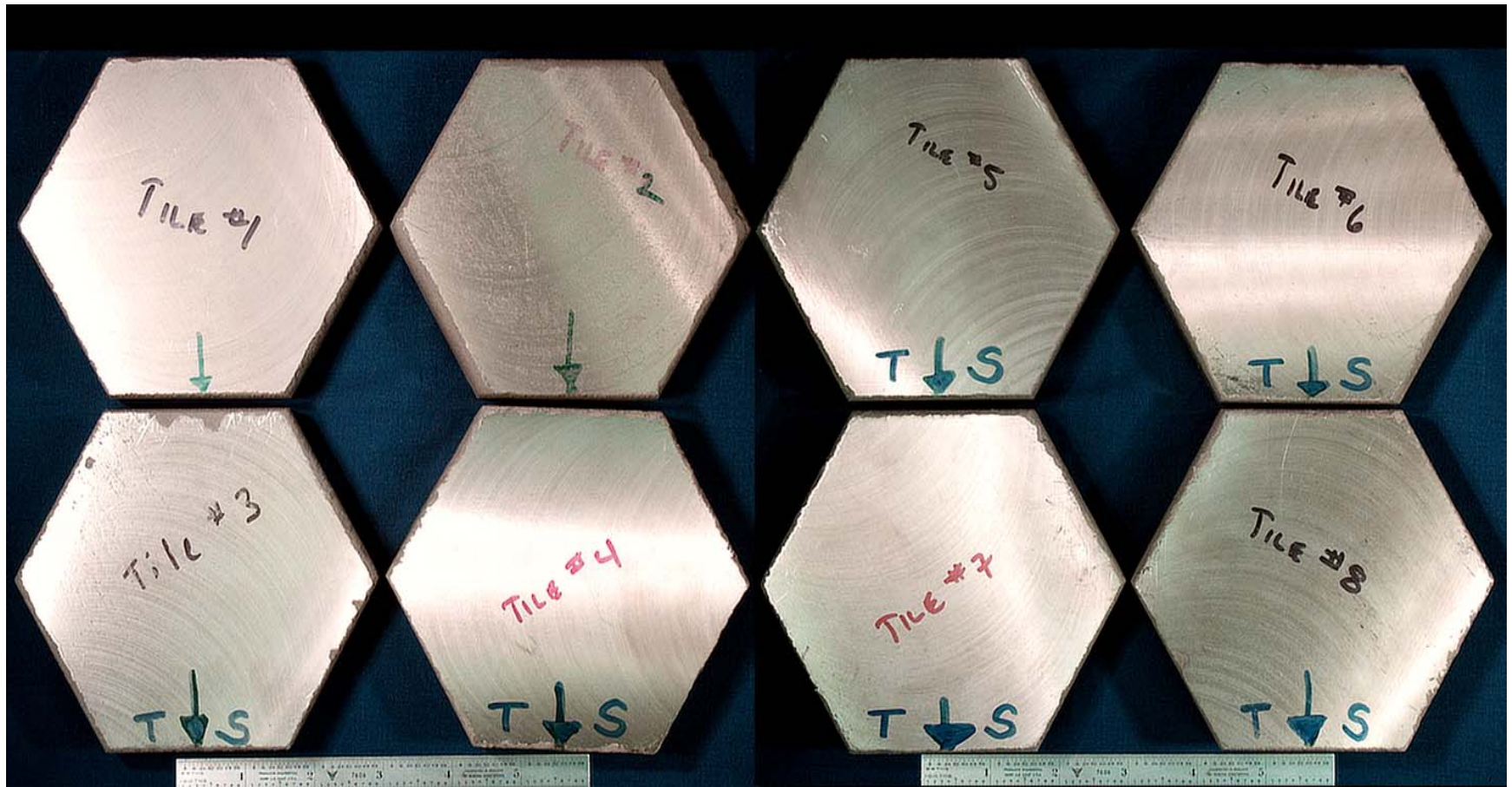
**As-received 4x4x.55in  $\text{Al}_2\text{O}_3$  ceramic tile prior to Cold Spray.**

**Initial test runs using sponge Ti displayed 'orange peel' surface (465).**

**Encapsulated tile (Tile #1).**



8  $\text{Al}_2\text{O}_3$  tiles encapsulated with .25in of Ti.





# **CERAMIC ARMOR TILE ENCAPSULATION**



## **Complete coating characterization studies:**

- \*adhesion, density, hardness, microstructure

## **Ballistically test encapsulated tiles:**

- \*perform hot isostatic pressing if required

## **Establish process parameters to encapsulate SiC tiles:**

- \* conduct cold spray simulation studies for Ti6Al4V
- \* investigate alternative coating materials
- \* encapsulate additional tiles with best candidate